

## Continuous Flow Measurements Using Ultrasonic Velocity Meters: An Update

Rick Oltmann, U.S. Geological Survey

An article in the summer 1993 *Newsletter* described USGS work to continuously monitor tidal flows in the delta using ultrasonic velocity meters. This article updates progress since 1993, including new installations, results of data analysis, damage during this year's high flows, and the status of each site.

UVMs operate by sending acoustic signals between two fixed transducers positioned on opposite sides of a channel; the acoustic path between transducers is oriented at about a 45-degree angle to the primary direction of flow. The UVM itself generally is placed in an instrument shelter on shore and connected to the transducers by transmission cables that lie on the channel bottom. Acoustic signals are transmitted in both directions across the channel, and signal travel times are measured precisely. The difference in time-of-travel for an upstream- and a downstream-transmitted signal provides a measure of the average velocity across the channel at the depth of the transducers. This velocity measurement is an index velocity (not mean cross-sectional velocity) and generally is referred to as a "line velocity". The line velocity is converted to total discharge by multiplying it by a coefficient and the channel cross-sectional area. The velocity coefficient is determined by calibration with measured discharges; the cross-sectional area is obtained using measured stage and channel geometry data. Generally, the UVM is programmed to provide a time series of tidal flow at a 15-minute interval; these data can be tidally averaged to estimate daily net flow. An acoustic Doppler discharge measuring system (Simpson and Oltmann 1992) is being used to make fast and accurate flow measurements for use in calibrating and validating the UVMs; the system uses an acoustic Doppler current profiler. Laenen (1985) provides details on operation of a UVM flow measurement station.

USGS has ten UVM flow monitoring stations in the delta that are either operational or in some phase of repair or installation. The oldest stations are the Sacramento River at Freeport (operational since 1979) and the Old River and Middle River sites adjacent to Bacon

Island (operational since 1987). The 1993 *Newsletter* article described the installation or planned installation of four additional UVM stations: Sacramento River upstream of the Delta Cross Channel, Sacramento River downstream of Georgiana Slough, San Joaquin River at Jersey Point, and Sacramento River downstream of Decker Island. All except the Decker Island station have been installed, and that station has been relocated upstream, at Rio Vista. Three additional stations have been or are being installed: Threemile Slough, Dutch Slough, and San Joaquin River at Stockton. Following is a discussion of the status of all these sites except Sacramento River at Freeport, along with available data analyses.

### Old River and Middle River

UVM stations on Old River and Middle River are on two of the three flow paths through which water is drawn to the SWP and CVP export facilities; the third route is from the San Joaquin River through Old River and Grant Line Canal. During low export periods, maximum tidal flow during both flood and ebb tides generally is about 10,000 cubic feet per second at both sites. Daily net flow data produced by the two stations for 1987-1992 indicate that about 80% of the combined SWP/CVP export rate is drawn from the north down Old and Middle rivers, and the other 20% is drawn from the east from the San Joaquin River.

Percentages of flow drawn through the three paths vary depending on the export rate, whether daily net flow of the San Joaquin River at Stockton is positive (to the north) or negative (to the south), and whether a temporary rock barrier is installed across Old River at the confluence with the San Joaquin River. When a temporary barrier is not installed and daily net San Joaquin flow at Stockton is positive, about 33% of the export water is drawn down Old River, 45% is drawn down Middle River, and 22% is drawn west from the San Joaquin River. Flow percentages for Old River and Middle River at the UVM sites increase by about 3% when daily net San Joaquin River

flow is negative, resulting in about a 6% decrease in the flow drawn west from the San Joaquin.

The data also show that flow percentages for Old River and Middle River decrease by 1-3% as the export rate increases throughout its range, indicating that the percentage of San Joaquin River water increases as the export rate increases. Installing a temporary notched, rock barrier at the head of Old River results in about a 64% reduction in flow of San Joaquin River water through Old River and Grant Line Canal; Old River flow increases to about 40%, and Middle River flow increases to about 52%.

This year is the only time since data collection at these stations began (in 1987) that net flows have been measured flowing to the north — away from the export facilities. From March 9 until June 14, 1995, San Joaquin River flow at Vernalis was high (over 10,000 cfs, with a maximum of about 26,000 cfs) and the combined SWP/CVP export rate was fairly low (less than 4,000 cubic feet per second). Maximum northerly net flows at the Old River and Middle River UVM sites were about 6,000 cfs on March 24, 1995.

### Sacramento River near Walnut Grove

The UVM station on the Sacramento River upstream of the Delta Cross Channel was operational from December 1992 until January 1995, when a rock barge destroyed a transducer pile. The Sacramento River station downstream of Georgiana Slough has been operational since January 1993.

The difference in flow records for these two stations provides an indirect measure of the flow passing through the Delta Cross Channel and Georgiana Slough when the cross channel gates are open and the flow through Georgiana Slough when the gates are closed. At the upstream site, tidal flows during low streamflow conditions range from ebb flows of about 13,000 cfs to flood flows of about 2,500 cfs; at the downstream site, ebb flows are about 10,000 cfs and flood flows are about 7,000 cfs.

Figure 1 shows how the tidal and tidally averaged flows vary at the two stations on the Sacramento River near Walnut Grove when the cross channel gates are alternately opened and closed. When the gates are open (days 295-301, 312-319), minimum tidal flows for the upstream site are ebb flows of about 4,000 cubic feet per second. When the gates are closed (days 302-304, 306-311), minimum tidal flows are slight flood flows of about 1,000 cfs. Opening and closing the gates has the opposite effect on tidal flows at the downstream site. When the gates are open, flood flows are at a maximum of about 7,000 cfs, and when the gates are closed flood flows decrease to about 4,000 cubic feet per second.

These data suggest that when the gates are open, flood flows moving up the Sacramento River past the downstream site encounter less resistance from the flow coming downriver past the upstream site relative to when the gates are closed. Thus, when the gates are open, flows past the sites are able to come together and move through the gates into the Delta Cross Channel. When the gates are closed, flood flow past the downstream site cannot enter the cross channel and, thus, exerts resistance to the ebb flow past the upstream site. This increased flow resistance decreases the magnitude of the flood flows at the downstream UVM site and decreases the magnitude of the ebb flows at the upstream site (at times, it even causes flood flows).

The two tidally averaged flow plots in Figure 1 indicate that when the Delta Cross Channel gates are closed, daily net Sacramento River flow past the upstream site decreases and daily net Sacramento River flow past the downstream site increases compared with when the gates are open. The decrease in net flow at the upstream site when the gates are closed results in increased flow from the Sacramento River into Sutter and Steamboat sloughs of about 1,800 cfs. This increase, along with the increase in net flow at the downstream site by about 2,000 cfs, results in an increased net flow of the Sacramento River at Rio Vista by about 3,800 cfs.

Replacement transducer mounting piles were driven at the damaged upstream site during August, and we hope to have the site operational in October.

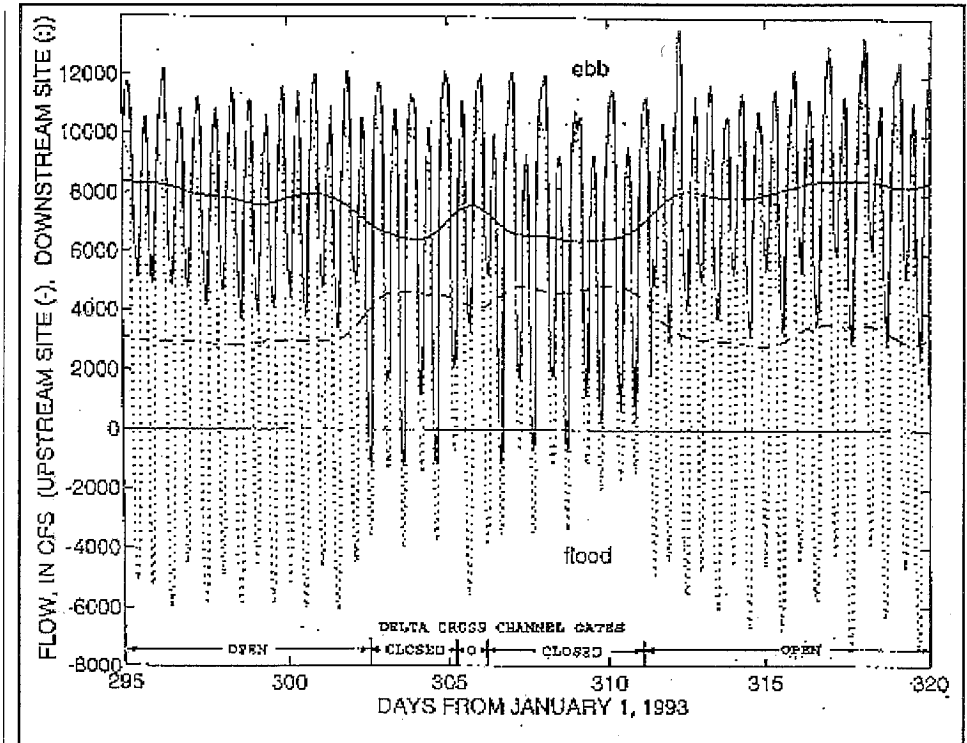


Figure 1  
TIDAL AND TIDALLY AVERAGED FLOWS FROM UVM STATIONS IN THE  
SACRAMENTO RIVER NEAR WALNUT GROVE

### San Joaquin River at Jersey Point

The Jersey Point UVM station was installed in May 1993, but because of instrumentation problems, it did not provide usable data until May 1994. At Jersey Point, the San Joaquin River is part of the deep water ship channel to the Port of Stockton. Depth is maintained by dredging — a hazard to transducer communication cables on the channel bottom. Therefore, a system of four transducers, one standard UVM, and a modified UVM called a "responder" was first used to create an acoustic link across the channel. The installation consisted of two transducers on one side of the channel connected by cable to a UVM and two transducers on the opposite side of the channel connected by cable to a responder. The UVM transmits an acoustic signal across the channel, and the signal is received by one of the transducers connected to the responder. The responder then initiates a return signal from the other transducer connected to the responder, which is received by the other transducer that is connected to the UVM. The time-of-travel of the acoustic signals is measured precisely and used as for a standard UVM installation.

Early operational problems of the Jersey Point system were thought to be related to the responder. To test this hypothesis, a temporary cable was laid across the channel bottom connecting one transducer from each side of the channel and eliminating the use of the responder. Use of the temporary cable resulted in good data from the UVM. Conversations with the Corps of Engineers revealed that dredging seldom occurs at this site. Therefore, an upgraded cable was deployed on May 11, 1994, and the site was operational until a passing vessel destroyed the transducer mounting piles on April 9, 1995. Replacement piles were driven in August, and the site should again be operational in October.

Flow data collected at Jersey Point before the transducer piles were destroyed showed that maximum tidal flow during both flood and ebb is about 150,000 cfs. Analysis of the tidally averaged net flow data demonstrates the filling and draining of the delta that occurs throughout the spring/neap tidal cycle. Figure 2 shows tidally averaged stage (top plot) and flow (bottom plot) for May 10 to October 26, 1994. Maximum combined Sacramento/San Joaquin inflow to the delta during this period was about 18,000 cfs. The vertical lines connecting the two

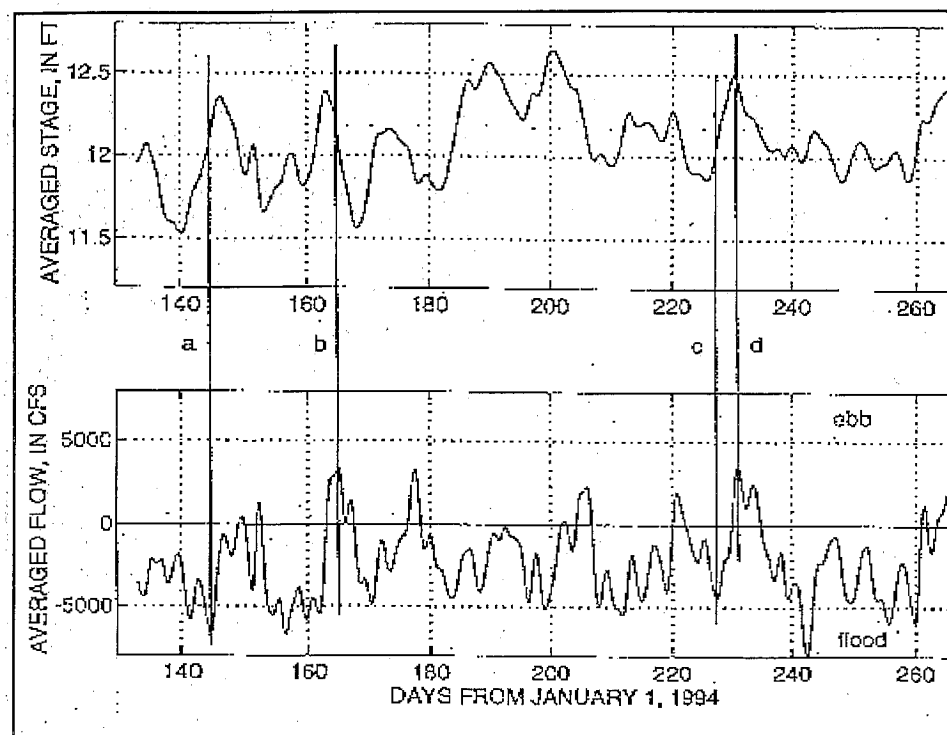


Figure 2  
TIDALLY AVERAGED STAGE (top) AND FLOW (bottom) FROM  
SAN JOAQUIN RIVER AT JERSEY POINT UVM

plots show that during spring tides, when the net elevation of the delta is rising (lines a and c), net flows into the delta (negative flow; delta is filling) are largest, and during neap tides, when the net elevation is decreasing (lines b and d), net flows out of the delta (positive flow; delta is draining) are largest. Figure 2 also shows that the average net flow during this predominantly summer period was about 2,000 cfs upriver.

### Threemile Slough

The Threemile Slough UVM station has been operational since February 1994. Maximum ebb and flood tidal flows are about 30,000 cfs. Net flow during conditions other than high flow is generally about 1,500 cfs from the Sacramento River to the San Joaquin River. The magnitude of this net flow varies with the spring/neap tidal cycle, with net flow being reduced as the delta drains and increased as the delta is filling. During the high flows of March 1995, maximum net flow was 22,300 cfs flowing from the Sacramento River to the San Joaquin River. For about 60 days following the peak, the net flow direction through the slough was periodically from the San Joaquin River to the Sacramento River, with a maximum net flow of about 2,000 cfs. The reversal of net flow direction

appears to result from high flows entering the delta from the San Joaquin River; San Joaquin River inflow to the delta during the 60-day period never was less than 17,000 cfs.

### Sacramento River at Rio Vista and Dutch Slough

Initially, a UVM installation was planned for the Sacramento River just downstream of Decker Island. The plan was to add flow from the Decker Island site to San Joaquin River flow at the Jersey Point site and to estimate flow through Dutch Slough to provide an estimate of delta outflow. The acoustic path length at the proposed Decker Island site was 3,000 feet, which exceeds the capability of the UVM equipment. Therefore, two complete UVM systems with responders (Sacramento Ship Channel), similar to the Jersey Point system, were initially planned for monitoring flow at this site. However, once funding was obtained for installation of the Threemile Slough UVM, we decided that the Decker Island station could be relocated upstream to the Rio Vista Bridge area and still provide the flow data necessary to estimate delta outflow. Three reasons for moving the Decker Island site upstream to Rio Vista were:

- To lessen the chance of obtaining erroneous line-velocity data due to bending of the acoustic signal because of salinity gradients within the acoustic path,
- To simplify installation and operation of the station by making use of the bridge structure, and
- To make use of a DWR compliance monitoring instrument shelter and stilling well.

During March 1995, installation began of two UVMs at the Rio Vista site. One is now operational; the acoustic path is on the northwest side of the channel. The acoustic path for the second UVM will be on the southeast side of the channel. The pile installed for the southeast acoustic path was lost during the March 1995 high flows; a steel replacement pile in addition to a support pile were installed during August. The two line velocities from the two UVMs will be used to compute the flow record. Because there will be two separate UVMs operating at this site, a radio link between the two will be required so that one UVM will be disabled while the other is measuring velocity.

The national ecosystem initiative program of the USGS funded installation of a UVM on Dutch Slough. This UVM station is needed to measure a small fraction of delta outflow. The equipment shelter has been installed, and the transducer mounting piles were driven during August. The site should be operational in November.

### San Joaquin River at Stockton

A UVM flow monitoring station was installed on the San Joaquin River near Stockton in July 1995, with funding provided by the City of Stockton. The site is about a half-mile north of the Highway 4 bridge crossing near the city waste water treatment plant. The National Pollutant Discharge Elimination System permit requires the city to obtain flow data at the location where treated effluent is discharged into the river. This site will monitor the periods and magnitude of net southerly San Joaquin River flow due to operation of the SWP and CVP export facilities and consumptive use in the southern delta. The instrument is recording line velocity and stage data, but it has not yet been calibrated.

### Supplemental Flow Data

The UVM network provides a valuable flow database for use in calibrating and validating delta flow and transport models. This database will be supplemented with ADDMS measurements collected periodically at critical flow splits to assess the accuracy of flow magnitude and phasing provided by models. An adequate number of measurements can be made with the ADDMS to simultaneously characterize tidal variations at three or four sites using one boat and a crew of two. The ADDMS is used to make a few measurements at each of the three or four sites in turn. Then the measuring cycle repeated for as long as desired; for example, during half or a complete tidal cycle.

### Acknowledgments

The USGS greatly appreciates the funding provided by DWR, USBR, Contra Costa Water District, and the City of Stockton to install and operate the network of UVM flow monitoring stations. The author acknowledges Mike Simpson, Steve Gallanthine (no longer with the project), Rick Adorador, and Scott Posey of the USGS for their dedicated effort in installing, troubleshooting, and operating the UVM network. Without their efforts, these valuable flow data would not have been collected.

### References

- Laenen, A. 1985. Acoustic velocity meter systems. *U.S. Geological Survey Techniques of Water Resources Investigations*, Book 3, Chapter A17. 38 pp.
- Simpson, M.R., and R.N. Oltmann. 1992. Discharge-measurement system using an acoustic Doppler current profiler with applications to large rivers and estuaries. USGS Open File Report 91-487. 49 pp.

### Feather River Fisheries Studies

Ted Sommer and Debbie McEwan, Department of Water Resources

The lower Feather River extends from Oroville to its confluence with the Sacramento River at Verona. Fall-run and spring-run chinook salmon spawn on two reaches of the river: the low-flow channel from Oroville to Thermalito Afterbay outlet, and the lower reach from Thermalito Afterbay outlet to Honcut Creek, near the town of Live Oak. The lower reach also provides important habitat for other migratory species such as American shad, splittail, striped bass, and green sturgeon.

Flow into the system is controlled by the Oroville complex, including Oroville Dam, Thermalito Diversion, and Thermalito Afterbay. Recently, Water Resources has initiated several fisheries studies in cooperation with Fish and Game. Major issues to be addressed include chinook salmon spawning, out-migration gravel quality, and the role of Feather River Fish Hatchery.

Flow conditions for salmon spawning were recently examined during development of an instream flow model for the Feather River. A key issue is whether the

model, which was based on measurements of spawning preferences during the 6-year drought, is applicable to higher flows. The present study will attempt to resolve this issue empirically by operating the low-flow channel at two different flow levels during the next 4 years. Beginning this fall, a combination of aerial photography and ground-based measurements will be used each year to determine spawning density, location, and conditions.

In early 1996, as part of efforts to provide comprehensive salmon monitoring in the Central Valley, Water Resources will install and operate screw traps below the low-flow channel and lower reach. We plan to operate the traps during winter and spring for at least the next 4 years to provide information about the timing and magnitude of juvenile salmon out-migration. We will also collect data on species such as splittail, green sturgeon, and steelhead.

Feather River Fish Hatchery plays a major role in the management of salmon and steelhead in the system. The hatch-

ery program is being evaluated by marking young salmon produced in the hatchery and in the river. The goals of this study are to determine:

- Distribution of adult Feather River salmon throughout the Sacramento Valley and the Pacific Ocean,
- Hatchery versus in-channel production,
- Conditions affecting juvenile survival.

In 1995, a total of 550,000 fish were tagged and released in the estuary. An additional 400,000 tagged juveniles have been released in the Feather River (200,000 fingerlings, 200,000 smolts). Some of the young salmon collected in the screw traps will also be tagged for comparison with hatchery-produced fish. The tagging program will continue at near the 1 million fish/year level through 1998. Fish and Game will recover the tags from the ocean fishery, returning adults in hatcheries, and carcasses in the Feather River and other streams.